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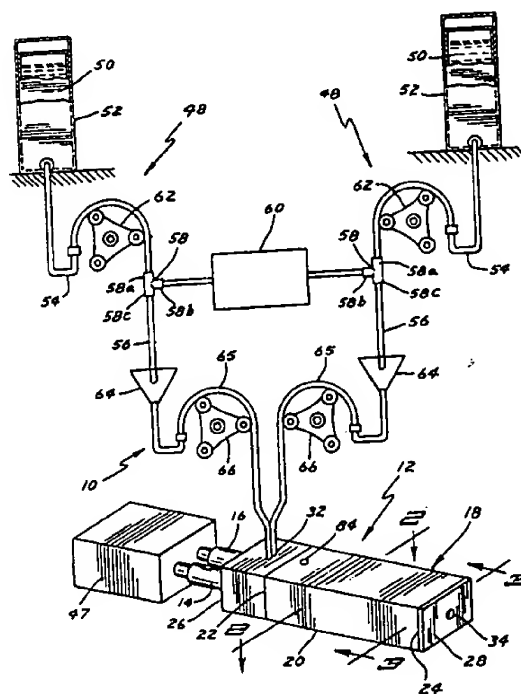
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(54) Title: TWIN SCREW EXTRUDER FOR BATCH FREEZING

(57) Abstract

An apparatus (10) for at least partially freezing a food product which is at least partly liquid in a batch mode is disclosed including a double screw extruder (12) including first and second, substantially intermeshing, self-wiping screws (14, 16) rotatably received in a figure 8-shaped barrel (30) with minimal clearance. In the preferred form, the freezing block (20) includes multiple refrigerant channels (36) spaced closely and in the most preferred form spaced approximately 0.32 centimeters from the barrel (30) and from each other. Thus, the refrigeration system can change the barrel surface temperature rapidly and specifically in approximately one second when the food product is introduced into the barrel (30). A ratio between the radius of the flight (40) at the crest (42) to the radius at the root (38) of the screws (14, 16) is in the order of 1.04 to reduce the total amount of product in the barrel (30) at any given time and decreasing the product residence time in the extruder (12). In the most preferred form, the food product is aerated and is supplied in discrete volumes from at least one and preferably from multiple sources (48), with the supply of discrete volumes for individual servings being delayed to substantially prevent intermixing in the extruder (12).



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1 Twin Screw Extruder for Batch Freezing

BACKGROUND

5 The present invention generally relates to at least partially freezing a food product which is at least partly liquid, specifically to at least partially freezing a food product in a batch process, and more specifically to dynamic freezing an aerated food product in a batch process.

10 To produce aerated frozen products such as frozen ice creams, frozen yogurts, or semi-frozen shakes, it is common to incorporate small air bubbles within the matrix of liquid ingredients before freezing. Incorporating air into the matrix of liquid ingredients is called aeration. It is also necessary to continually disturb or scrape the aerated ingredients at the surface of the heat exchanger while freezing the product. Freezing while disturbing the surface of the heat exchanger is called dynamic freezing. Failure to disturb or scrape the surface will cause a migration of the entrapped air away from the chilled surface and will result in a dramatic loss of air content in the frozen product.

15 Dynamic freezing of an aerated product can be accomplished in a dynamic freezing reservoir type apparatus described in U.S. Patents 3,904,085; 3,954,126, and 4,201,588. Aeration and dynamic freezing is accomplished by these reservoir type apparatus simultaneously through a combination of metering in air and liquid ingredients, of beating the matrix of liquid ingredients and of continuously scraping the inner wall of a cylindrical heat exchanger with an auger which eventually whips air into the matrix of liquid ingredients

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1 gradually as the product is being frozen in a dynamic
fashion. The cylindrical heat exchanger holds and
continuously processes a volume of product equal to a
multiple of individual servings. Due to the gradual and
5 continuous nature of the process, control over the amount
of air incorporated into the matrix of the liquid
ingredients, known as "overrun", is limited.

One disadvantage of the apparatus of the dynamic
freezing reservoir type described in these three patents
10 is that the heat transfer rate is relatively low due to
the comparatively moderate mass transfer of the product
at the chilled surface due to a relatively low ratio of
surface area of the inner wall of the heat exchanger
versus the volume of the heat exchanger and of the liquid
15 ingredients in the reservoir. Lower heat transfer rates
equate to a longer time to freeze the product. During
periods of high demand on apparatus of the dynamic
freezing reservoir type, the charge of adequately frozen
product is frequently exhausted, leaving a large volume
20 of partially frozen product in the reservoir. A recovery
time is necessary during which the product is dynamically
frozen and during which no servings may be withdrawn.
This recovery time is typically on the order of ninety
seconds.

25 A further disadvantage of the apparatus of the dynamic
freezing reservoir type is that a relatively large volume
of product must remain in the heat exchanger at all times.
During periods of slow demand, the product in the heat
exchanger of the apparatus of the dynamic freezing
30 reservoir type has the opportunity to degrade in texture
and flavor. This results in a significant detectable drop
in product quality.

Another disadvantage of the large volume of product
in the reservoir in apparatus of the dynamic freezing
35 reservoir type is the necessity to completely remove the
contents of the heat exchanger before it is possible to
change from one product to another. As it is not

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1 practical to empty the contents of the heat exchanger
between individual servings, apparatus of the dynamic
freezing reservoir type includes separate heat exchangers
for each product desired to be dispensed, such as one heat
5 exchanger for chocolate and another heat exchanger for
vanilla. Individual servings are then dispensed from
one or the other of the heat exchangers or simultaneously
from both producing a "swirl."

Still another disadvantage of apparatus of the dynamic
10 freezing reservoir type is the necessity to discard the
entire contents of the heat exchanger any time operation
is desired to be interrupted such as for cleaning.
Specifically, to dispense an individual serving from
the heat exchanger, it is necessary to introduce a
15 corresponding volume of the liquid ingredients into the
heat exchanger. Thus, when it is desired to clean the
apparatus, it is not possible to dispense the contents of
the heat exchanger to empty the heat exchanger but rather
the contents must be manually removed or forced from
20 inside the heat exchanger such as by the introduction of
water or similar cleaning fluid. But in any case, the
contents of the heat exchanger must be discarded resulting
in an increase in overall material costs for the operator.

An alternate means for producing aerated frozen
25 products is to utilize a two-step process where the liquid
ingredients are first aerated in an aeration system and
then the aerated liquid ingredients are dynamically frozen
in a freezing system. A major advantage of aerating the
liquid ingredients prior to dynamic freezing is that
30 aeration can be achieved with more positive control of
overrun.

An improved means of achieving aeration is described
in U.S. Patents 5,292,030; 5,433,967; and 5,473,909. In
apparatus disclosed therein, air is incorporated into the
35 matrix of the liquid ingredients by means of the rapid
transport of the liquid ingredients through a turbulence
tube of specific diameter and length by means of a copious

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1 amount of compressed air at a specific pressure which is
high enough to ensure turbulent flow. By selecting
appropriate turbulence tube dimensions and air pressures,
a predictable overrun can be achieved with more positive
5 control than was possible when using the aeration method
of the dynamic freezing reservoir type. A drawback to
this method of aeration is that only a small percentage
of the compressed air used for aeration gets incorporated
into the liquid ingredient matrix and the large percentage
10 of the compressed air which does not get incorporated must
be exhausted from the apparatus. Positively, the product
does not necessarily come into direct contact with any
surfaces that would need to be cleaned, with the exception
of the turbulence tube itself which could be formed to be
15 disposable.

An alternate means of achieving aeration is described
in U.S. Patent 5,345,781. Aeration may also be
accomplished through the use of a high speed shearing
mixer which combines air and liquid together while
20 mixing air into the liquid ingredient matrix. There
are numerous examples of high speed shearing mixers in
industry. While not requiring the exhaust of excess air
that the turbulence tube method entails, there would be
significant additional sanitation demands due to the
25 direct contact of food product within aeration devices
of this type.

Various approaches to providing dynamic freezing of
a previously aerated product exist. As an example, U.S.
Patent 5,345,781 provides a freezing and transporting
30 twin screw extruder. The threads of the second screw
are centered between the threads of the first screw and
operation is continuous. Specifically, operation involves
the production of a volume of product equal to a multiple
of individual servings and would normally be utilized in
35 a large scale industrial environment for continuous
operation and not operated in a retail environment where

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1 individual servings would be sold such as restaurants,
drive-ins, and the like.

Embodiments of apparatus described in U.S. Patents
5,292,030; 5,433,967; and 5,473,909 discharge an aerated
5 liquid onto a thermally conductive plate having relative
movement to a scraper for scraping the thin film of
frozen product from the plate. This approach has special
application in batch production. Specifically, only the
volume of aerated product corresponding to the desired
10 volume of frozen product to be dispensed is discharged
onto the thermally conductive plate so that only a single
batch or serving of frozen product is frozen. A batch
process refers to the production of only a single serving
of product as opposed to the simultaneous production of
15 multiple servings whether dispensed continuously or
individually. Additionally, the scraper can be designed
and arranged so that substantially all of the frozen
product is scraped from the thermally conductive plate
leaving minimal frozen product on the thermally conductive
20 plate which will mix with the next discharge of aerated
liquid onto the thermally conductive plate. This mixing
of product between individual servings is referred to as
carryover. The advantage of very minimal product
carryover from serving to serving on the thermally
25 conductive plate makes it possible to change from one
product to another between individual servings. Further,
this thin film type freezing can be accomplished more
rapidly than reservoir type freezing. Furthermore, when
it is desired to interrupt operation, it is not necessary
30 to discard any product. Apparatus of the thin film
freezing type avoids many of the other disadvantages
of apparatus of the dynamic freezing reservoir type.
However, due to its quiescent nature of being frozen as
a thin film and being simply scraped from the thermally
35 conductive plate, the final frozen product has different
ice crystal and air cell morphology as well as a higher

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1 amount of water in a frozen state and a lower volume of
air, resulting in a brittle, less pliable texture.

U.S. Patent 3,803,870 discloses a machine for the
instantaneous production of ice cream of one or more
5 flavors in a batch process. In apparatus disclosed
therein, a liquid or a combination of liquids is frozen
in a freezing chamber provided with a cylindrical screw
having its axis inclined to the horizontal. A tank
including sweetened wash water is provided for washing
10 the machine at the end of production of each unit batch
of ice cream in order to cleanly separate the flavors of
one unit batch from the flavors of the batch which
follows, if required. It is assumed that such washing
would be required whenever the flavor desired to be
15 dispensed is different than the flavor of the proceeding
batch due to the inability of a single screw to remove
all material from the flights of the screw in operation.

Thus, a need continues to exist for apparatus and
methods for at least partially freezing a food product
20 which is at least partly liquid and which have very
minimal product carryover from serving to serving thus
allowing operation in a batch process and which provide
dynamic freezing of an aerated food product with a better
control of overrun levels.

25 SUMMARY

The present invention solves this need and other
problems in the field of at least partially freezing a
food product which is at least partly liquid by providing,
in the preferred form, first and second, substantially
30 intermeshing, self-wiping screws rotatably received in
a figure 8-shaped barrel with minimal axial and radial
clearance, with the barrel being chilled to freeze the
food product at the inner wall of the barrel for being
continually scraped therefrom by the first and second
35 screws. In the preferred form, operation is in a batch
mode where delivery of discrete volumes of the food
product to the twin screws is delayed until after the

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1 first and second screws have conveyed the prior delivery
of food product sufficiently to prevent intermixing.

It is thus an object of the present invention to
provide novel apparatus and methods for at least partially
5 freezing a food product which is at least partly liquid.

It is further an object of the present invention to
provide such novel apparatus and methods for at least
partially freezing a product in a batch process.

It is further an object of the present invention to
10 provide such novel apparatus and methods for producing a
series of individual single servings of at least partially
frozen aerated product.

It is further an object of the present invention to
provide such novel apparatus and methods for at least
15 partially freezing a properly aerated liquid.

It is further an object of the present invention to
provide such novel apparatus and methods ensuring proper
overrun in at least partially frozen aerated product.

It is further an object of the present invention to
20 provide such novel apparatus and methods for extruding at
least partially frozen aerated product at a rate of up to
two ounces per second.

It is further an object of the present invention to
provide such novel apparatus and methods for minimizing
25 the amount of product in the freezing chamber at all times
to ensure that the individual servings will always be
fresh.

It is further an object of the present invention to
provide such novel apparatus and methods for at least
30 partially freezing an aerated liquid as rapidly as
possible.

It is further an object of the present invention to
provide such novel apparatus and methods for at least
partially freezing an aerated liquid using the smallest
35 volume freezing chamber possible.

It is further an object of the present invention to
provide such novel apparatus and methods for self cleaning

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1 the freezing chamber to further reduce the amount of
product carried over from one individual serving to the
next.

It is further an object of the present invention to
5 provide such novel apparatus and methods for extruding at
least partially frozen product through a die that forms
the frozen product into an extrudate that can be captured
in a cup, edible cone or similar container.

It is further an object of the present invention to
10 provide such novel apparatus and methods for pressurizing
the aerated liquid product at the entrance to the freezing
chamber to provide for increased pumping efficiency.

These and further objects and advantages of the
present invention will become clearer in light of the
15 following detailed description of illustrative embodiments
of this invention described in connection with the
drawings.

DESCRIPTION OF THE DRAWINGS

The illustrative embodiments may best be described by
20 reference to the accompanying drawings where:

Figure 1 shows a diagrammatic view of an apparatus
utilizing methods for at least partially freezing of an
aerated food product in a batch mode according to the
preferred teachings of the present invention.

25 Figure 2 shows a cross-sectional view of the apparatus
of Figure 1 according to section line 2-2 of Figure 1.

Figures 3a, 3b, 3c, 3d and 3e show cross-sectional
views of the apparatus of Figure 1 according to section
line 3-3 of Figure 1 in 9° intervals of rotation.

30 Figure 4 shows a diagrammatic, cross-sectional view of
an alternate embodiment of a chilled screw extruder for
the apparatus of Figure 1.

All figures are drawn for ease of explanation of
the basic teachings of the present invention only;
35 the extensions of the Figures with respect to number,
position, relationship, and dimensions of the parts to
form the preferred embodiments will be explained or will

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1 be within the skill of the art after the following
description has been read and understood. Further, the
exact dimensions and dimensional proportions to conform to
specific force, weight, strength, and similar requirements
5 will likewise be within the skill of the art after the
following description has been read and understood.

Where used in the various figures of the drawings,
the same numerals designate the same or similar parts.
Furthermore, when the terms "top", "bottom", "first",
10 "second", "inside", "outside", "front", "back", "outer",
"inner", "upper", "lower", "height", "width", "length",
"end", "side", "horizontal", "vertical", "axial",
"radial", "longitudinal", "lateral", and similar terms are
used herein, it should be understood that these terms have
15 reference only to the structure shown in the drawings as
it would appear to a person viewing the drawings and are
utilized only to facilitate describing the illustrative
embodiments.

DESCRIPTION

20 Apparatus for at least partially freezing a food
product which is at least partly liquid in a batch
process according to the preferred teachings of the
present invention is shown in the drawings and generally
designated 10. In the most preferred form, apparatus 10
25 has special application for the dynamic freezing of an
aerated food product. However, apparatus 10 according to
the teachings of the present invention also can be used
for at least partially freezing other food products
including aerated and nonaerated beverages as well as
30 other non-food products which are at least partly liquid.
Generally, apparatus 10 includes a double screw extruder
12 having substantially intermeshing, self-wiping screws
14 and 16 rotatable inside of a housing assembly 18.
Screws 14 and 16 can include suitable rotary mechanical
35 seals 19 such as disclosed in U.S. Patent 5,345,781 for
sealing the shaft ends of screws 14 and 16 to housing

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1 assembly 18 to prevent product from leaking along the
shafts of screws 14 and 16.

Assembly 18 generally includes in the preferred form
a freezing block 20 having an upstream end 22 and a
5 downstream end 24, an inlet block 26 and an exit plate
28. Inlet block 26 is removably secured to and covers
upstream end 22 and exit plate 28 is removably secured
to and covers downstream end 24. Assembly 18 includes a
barrel or channel 30 of a figure 8-shape of a size and
10 configuration corresponding to intermeshing screws 14 and
16 and specifically providing minimal screw-to-barrel
clearance.

Barrel 30 extends from downstream end 24 through block
20 and upstream end 22 and terminates in the interior of
15 inlet block 26. Inlet block 26 includes an entrance port
32 extending from the exterior thereof and terminating
and in fluid communication with barrel 30 in the interior
thereof. Exit plate 28 includes an exit port 34 extending
from the exterior thereof and terminating and in fluid
20 communication with barrel 30 of freezing block 20 and in
particular overlying the intermeshing area of co-rotating
screws 14 and 16 as in the most preferred form of the
present invention. In one preferred form, exit plate 28
functions as a die that forms the product passing through
25 exit port 34 into an extrudate that can be captured in
a cup, an edible cone or similar container. In the
preferred form, the ratio of the length of barrel 30 from
the center of entrance port 32 to the inside surface of
exit plate 28 versus the outside diameters of screws 14
30 and 16 is in the order of 3 and in the preferred form
in the range of 1.5 to 6, particularly in the range of
2 to 4 and in the most preferred form in the range of
2.5 to 3.5.

Multiple refrigerant channels 36 extend through at
35 least freezing block 20 spaced closely adjacent and
parallel to barrel 30 for chilling freezing block 20 and
parallel to the axes of rotation of screws 14 and 16 and

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- 1 positioned at a distance relative to each other.
Specifically, the temperature at the inner mantle surface
of barrel 30 should be in the order of -8°F (-22°C) and in
the preferred form in the range of -20° to $+4^{\circ}\text{F}$ (-29° to
5 -15°C), particularly in the range of -15° to -1°F (-26°
to -18°C), and in the most preferred form in the range of
 -9° to -7°F (-22° to -21.6°C). Inlet block 26 and exit
plate 28 can either be directly chilled or not depending
upon the requirements of the liquid being processed.
- 10 In the most preferred form, channels 36 are located
exclusively in freezing block 20 to allow removal of
inlet block 26 and exit plate 28 from freezing block 20
for cleaning without requiring the source of refrigerant
or coolant from being disconnected and specifically from
15 being disconnected from freezing block 20.

In the most preferred form, first and second rows of
channels 36 are provided parallel to but at different
radial spacings from barrel 30. In this arrangement,
the first row of channels 36 is provided for rapid
20 temperature response to minimize recovery time and the
second row of channels 36 is provided for increasing the
total amount of heat transfer in housing assembly 18. As
diagrammatically illustrated in Figure 4, freezing block
20 is formed of upstream, intermediate, and downstream
25 portions 20a, 20b, and 20c which are integrally secured
together. An inlet port 82 is formed in upstream portion
20a and intersects with a plenum which is in simultaneous
fluid communication with the upstream ends of each of the
channels 36 in the first row. Downstream portion 20c
30 includes a plenum which is in simultaneous fluid
communication with the downstream ends of each of the
channels 36 of the first and second rows. An exit port 84
is also formed in upstream portion 20a and intersects with
a plenum which is in simultaneous fluid communication
35 with the upstream ends of each of the channels 36 in the
second row.

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1 In preferred applications, assembly 18 is made of a
highly thermally conductive material such as aluminum or
an aluminum alloy. In other applications, assembly 18
may be made of carbon, alloy steel, or other materials.
5 In addition, plated or coated materials could be used.
Assembly 18 is designed to minimize the thermal mass and
maximize the thermal response of the refrigeration system
to enable close control over the inner wall temperatures
of barrel 30. Since convective heat transfer between the
10 refrigerant and cooling channels 36 is the limiting factor
in removing heat, the number of channels 36 should be
maximized based upon geometric and structural constraints.
Generally, in the preferred form, minimizing thermal mass
entails minimal wall sections between barrel 30 and
15 channels 36 and between channels 36 themselves while
maintaining structural integrity and in the most preferred
form the distance between barrel 30 and channels 36 and
between channels 36 is approximately 1/8 inch (0.32 cm)
and in the preferred form in the range of 1 to 5
20 millimeters. This represents a significant reduction in
thickness from typical housings for continuous process
twin screw extruders. One reason this is possible is
that the process of apparatus 10 of the present invention
operates at near atmospheric pressure conditions and the
25 need for thick wall construction due to high pressure
operation is reduced considerably. The thin wall section
separating cooling channels 36 from barrel 30 offers
little thermal conduction resistance. This allows the
refrigeration system to change the wall temperature of
30 barrel 30 rapidly in response to a possible increase in
wall temperature due to the introduction of a relatively
warmer food product. The rapid response allows apparatus
10 of the present invention to operate on a batch mode
basis. In other words, freezing block 20 can be emptied
35 out and then refilled with product at a later time without
ever getting either too cold when empty, or too warm with
the fresh introduction of relatively warmer product.

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1 However, it can be appreciated that other provisions
can be utilized according to the teachings of the present
invention for chilling block 20 other than through the
use of circulating refrigerant or coolant through channels
5 36 including but not limited to flooding block 20 with a
refrigerant or coolant.

As best seen in Figures 2 and 3, screws 14 and 16
are of identical construction and phased to allow
intermeshing. Generally, screws 14 and 16 each include
10 a shaft cylinder with a mantle surface or root 38 having
an outer periphery generally concentric to the axis of
rotation and having a constant diameter along the entire
axial length. Screws 14 and 16 each further include a
flight 40 disposed on root 38 and having a pitch in the
15 order of 1.6 times the diameters and in the preferred
form in the range of 0.4 to 2.4 times the diameters,
particularly in the range of 1.2 to 2 times the diameters,
and in the most preferred form in the order of 1.5 to 1.7
times the diameters. Flight 40 has a crest 42, a leading
20 face 44 and a trailing face 46. In the most preferred
form, faces 44 and 46 are not linear and have an
increasing size from crest 42 to root 38. The thickness
of flight 40 between faces 44 and 46 is much smaller than
the axial width of the channel defined by flight 40.
25 Screws 14 and 16 are positioned parallel to each other
and further positioned such that the threads of screw 16
formed by flight 40 are located between the threads of
screw 14 formed by flight 40. In the preferred form,
crest 42 of screw 14 closely sweeps root 38 of screw 16
30 and crest 42 of screw 16 closely sweeps root 38 of screw
14 with minimal clearance. Additionally, as best seen in
Figure 3, crest 42 of at least one of the screws 14 and 16
is always sweeping the other of the screws 14 and 16 in
every rotational position of screws 14 and 16. It should
35 be appreciated that screws 14 and 16 having 5 lobes
generally repeat the relative rotation positions every 36°
of rotation as best seen when comparing Figures 3a and 3e.

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1 In the preferred form and at 70°F (32.4°C) of block
20 and screws 14 and 16, a ratio of the radial screw
clearance, which is defined as the difference between the
radius of barrel 30 and the outside radii of screws 14
5 and 16 or in other words the spacing between crests 42 of
flights 40 of screws 14 and 16 and barrel 30, versus the
radius of flights 40 of screws 14 and 16 is in the order
of 0.006, and in the preferred form in the range of 0.002
to 0.010, particularly in the range of 0.003 to 0.009 and
10 in the most preferred form in the range of 0.005 to 0.007.
Further, as best seen in Figure 2, faces 44 and 46 in the
preferred form are profiled such that face 44 of screw 14
closely sweeps face 46 of screw 16 with minimal clearance
at all rotational positions of screws 14 and 16.
15 Specifically, screws 14 and 16 are designed with no
clearance between faces 44 and 46, with the clearance
between faces 44 and 46 being less than 0.5% of the
diameter of screws 14 and 16 and preferably less than
0.25% of the diameter of screws 14 and 16 during operation
20 of apparatus 10 according to the teachings of the present
invention.

This close sweep action between screws 14 and 16
provides a self-wiping action preventing the buildup and
degradation of material on the surfaces of screws 14 and
25 16. Similarly, the minimal screw-to-barrel clearance
provides a self-wiping action preventing buildup and
degradation of material on the wall surfaces of barrel 30.
Buildup and degradation of material can result in product
contamination and unstable conditions. Flights 40 can
30 be fabricated to have generally anywhere from one to six
lobes with five lobes being shown in Figure 3.

In the most preferred form, screws 14 and 16 are
rotated by a suitable drive 47 to both rotate in the same
direction, in other words co-rotating, at a speed in the
35 order of 100 RPM and in the preferred form in the range
of 60 to 140 RPM, particularly in the range of 80 to
120 RPM, and in the most preferred form in the range of

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1 90 to 110 RPM. Co-rotating screws 14 and 16 are
advantageous. Specifically, problems of calendering which
can occur with screws rotating in opposite directions,
in other words, counter-rotating screws, are avoided.
5 Particularly, product in the gap between counter-rotating
screws tend to force apart the screws such that product
can remain in the barrel intermediate the screws.
Further, such forces also put pressure between the crests
of the flights and the barrel causing excess wear of the
10 flights and resulting in heat generation.

In another embodiment of the present invention, one or
both screws 14 and 16 are provided with inner cooling in
addition to the cooling of housing assembly 18. In the
form as shown in Figure 4, roots 38 of each screw 14 and
15 16 are substantially hollow and specifically include a
cylindrical bore 70 extending axially from the axial,
upstream, driven end towards but axially spaced from the
axial, downstream end of screws 14 and 16. Each of the
screws 14 and 16 further includes a cylindrical stationary
20 post 72 having a diameter slightly smaller than the
diameter of bore 70 and an axial length greater than that
of bore 70. Post 72 is positioned such that its axially
free end is located closely adjacent to the axially inner
end of bore 70, with screws 14 and 16 being rotatable
25 about posts 72 such as by being rotatably supported on
posts 72 by bearings 73. Suitable seals 74 are provided
between bores 70 and posts 72. Screws 14 and 16 can be
rotated relative to posts 72 and housing assembly 18 such
as by sprockets secured to screws 14 and 16 and positioned
30 axially outward of housing assembly 18.

Each post 72 includes at least one inlet conduit 76
extending axially from the axially free end of post 72
and is suitably connected to a source of refrigerant or
coolant. Each post 72 further includes at least one
35 return conduit 78 extending from a point axially spaced
outward of the axially free end of post 72 and suitably
connected to the source of refrigerant or coolant. Each

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1 return conduit 78 includes a plurality of apertures 80
extending between the cylindrical outer face of post 72
and conduit 78, with apertures 80 being spaced in an axial
direction along the axial extent of post 72 located inside
5 seal 74 and bore 70.

In operation, low temperature refrigerant or coolant
travels from the source through inlet conduit 76 of post
72 into the interior of screws 14 and 16 and specifically
inside of bores 70. The refrigerant or coolant travels
10 from the volume between the axially free end of post 72
and the axially inner end of bore 70 to the volume
between the cylindrical faces of bore 70 and post 72.
The refrigerant and coolant then travels through apertures
80 into conduit 78 back to the source. It should be
15 appreciated that apertures 80 are sized such that some
refrigerant and coolant must travel the full axial length
of bore 72 inside of seal 74 to insure cooling the full
axial length of screws 14 and 16. Freezing of the liquid
on the surfaces of screws 14 and 16 in addition to the
20 surface of barrel 30 can then occur, and to insure dynamic
freezing, constant self wiping of and between screws 14
and 16 is required.

Co-rotating twin screws 14 and 16 according to the
teachings of the present invention have a distinct
25 advantage over simple single augers such as taught in
U.S. Patent 3,803,870. Specifically, through the action
of dual rotation, the product passes from one screw to
another as it is also being scraped and transported along
the axes of screws 14 and 16. This action yields a
30 significantly higher mass transfer of the product along
the inner wall of barrel 30. One of the factors in
extracting heat, among other things, is the mass transfer
of the liquid being chilled. By maximizing the mass
transfer, the heat transfer can also be maximized which
35 in turn reduces the amount of time that the product must
necessarily be in contact with the chilled surface which
would reduce the overall size necessary for the chilled

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1 surface. So increasing the rate of heat removal yields
the double benefit of reduced product residence time in
the freezing chamber and smaller freezing chamber size.

Additionally, co-rotating twin screws 14 and 16
5 according to the present invention employ a ratio between
the radius of flight 40 at crest 42 to the radius at root
38 in the order of 1.04 and in the preferred form in the
range of 1.01 to 1.2, particularly in the range of 1.02 to
1.07, and in the most preferred form in the range of 1.03
10 to 1.05. This is not a typical design for twin screw
extruders which normally have a ratio in the order of 1.5
to 2, with extruders for plastic for compounding purposes
being in the low range, extruders for continuous mixing of
doughs being in the high range, and cooking extruders for
15 expanded products such as for pet foods and snacks being
in intermediate ranges.

Screws 14 and 16 according to the teachings of the
present invention reduce the total amount of product
in the screw chamber at any given time while at the same
20 time further decreasing the residence time necessary in
assembly 18 by increasing the specific heat transfer
(heat extracted per second per ounce of product). The
ratio of the free volume of product in the screw chamber
to the chilled surface area of barrel 30 is much lower
25 than with typical twin screw applications to take
advantage of exposing the product to a relatively large
chilled surface area. This ratio can be further greatly
reduced if screws 14 and 16 are themselves chilled and are
included in the chilled surface area calculation. Both
30 of these ratios help quantify the ability of extruder 12
according to the preferred teachings of the present
invention to rapidly remove heat from the liquid product.

When compared to counter-rotating screws or single
screw systems, the amount of heat added to extruder 12
35 through friction between screws 14 and 16 and the wall
surface of barrel 30 and through the energy dissipation
into the product has been minimized through the use of

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1 co-rotating twin screws 14 and 16 with carefully selected
geometric dimensions.

According to the preferred teachings of the present
invention, extruder 12 is utilized and has special
5 application to dynamically freeze an aerated liquid and
in particular to produce an aerated frozen product such
as frozen ice cream, frozen yogurt, semi-frozen shakes,
and the like. In particular, one or more sources 48 of
a properly aerated liquid is in fluid communication with
10 entrance port 32 of assembly 18 of extruder 12, with two
sources 48 being shown. In the most preferred form, each
source 48 includes a plastic bag 50 of at least a partly
liquid food product such as an ice cream base, with the
product being held at atmospheric pressure. In the most
15 preferred form, bag 50 is located in a carton 52 such as
formed of cardboard. A length of flexible tubing 54 is
in fluid communication with bag 50 such as by suitable
fixtures. For achieving aeration, a turbulence tube 56 is
utilized of the type of U.S. Patents 5,292,030; 5,433,967;
20 and 5,473,909. In particular, a T-fitting 58 is provided
having a first leg 58a connected to the downstream end of
tubing 54, a second leg 58b connected to a source 60 of
air or other gas under pressure, and a third leg 58c
connected to the upstream end of turbulence tube 56.
25 The liquid food product within bag 50 is pumped or
otherwise forced through tubing 54 into fitting 58 such
as by a conventional peristaltic pump 62 which engages
and compresses tubing 54. As set forth in U.S. Patents
5,292,030; 5,433,967; and 5,473,909, the air and liquid
30 food product are mixed together and forced along
turbulence tube 56 so that by the time the liquid leaves
turbulence tube 56, the liquid food product is properly
aerated to the proper overrun level.

When utilizing turbulence tube 56, it is necessary to
35 remove excess air that does not get incorporated into the
liquid food product but acts only to transport the liquid
food product and aerated liquid through turbulence tube

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1 56 before the aerated frozen product leaves extruder 12
through exit port 34. In a preferred form, turbulence
tube 56 delivers the aerated liquid and excess air to a
collection vessel 64 which is open to atmosphere allowing
5 the excess air to escape therefrom. A length of flexible
tubing 65 is in fluid communication between vessel 64 and
entrance port 32. The aerated liquid product within
vessel 64 is pumped or otherwise forced through tubing 65
into entrance port 32 such as by a conventional peristaltic
10 pump 66 which engages and compresses tubing 65. In the
preferred form, the aerated liquid product is forced into
entrance port 32 of extruder 12 under a pressure greater
than atmospheric pressure and in the most preferred form
at a pressure in the order of 40 psi (2.8 bars) by pump
15 66. It has been found that when aerated liquid is force
fed into extruder 12, feed rates of 150% to 300% are
obtained as compared to when aerated liquids are simply
fed by gravity at atmospheric pressures into extruder 12.
It should be appreciated that other manners of removing
20 excess air and for force feeding the aerated liquid can be
utilized. For example, turbulence tube 56 could deliver
the aerated liquid and excess air directly into entrance
port 32 and assembly 18 could include suitable provisions
for venting the excess air from extruder 12 separate from
25 exit port 34. Also, turbulence tube 56 could deliver
the aerated liquid and excess air to a small plenum in
communication with entrance port 32 of extruder 12. This
small plenum could include a relief valve to maintain a
positive gage pressure inside of the small plenum to
30 pressurize the aerated liquid as it flows through entrance
port 32 and into extruder 12.

In the most preferred form of the present invention,
source 48 utilizes turbulence tube 56 for aeration and is
believed to be advantageous at least due to its simplicity
35 and ease of sanitation. There are, however, other manners
of providing a properly aerated product to extruder 12
such as but not limited to high speed mixers.

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1 Additionally, although in the preferred form a two-step
process is utilized where the liquid product is aerated
before its introduction into extruder 12, other methods
of the dynamic freezing of an aerated liquid product can
5 be utilized including but not limited to where air under
pressure is introduced with the liquid product directly
into extruder 12 where aeration and dynamic freezing are
accomplished simultaneously.

The improved heat transfer rate in combination with
10 the reduced amount of product at any given time inside
barrel 30 allows extruder 12 according to the teachings
of the present invention to freeze up to two ounces per
second of aerated product. The time necessary from
activating the filling and freezing process up to the
15 start of product exiting exit port 34 is less than seven
seconds and preferably less than four seconds. This is
a substantial improvement over prior art reservoir type
freezing which normally requires a ninety second recovery
time.

20 The reduced free volume of product in the screw
chamber also allows the operation of extruder 12
according to the teachings of the present invention in a
non-continuous, batch mode for dispensing individual fresh
servings on demand. In particular, the product to be at
25 least partially frozen is supplied to extruder 12 by
source 48 in discrete volumes corresponding to the volume
of frozen product desired to be dispensed. Screws 14 and
16 are rotated sufficiently between the supply of discrete
volumes such that the frozen product of one volume has
30 substantially passed through exit port 34 before the next
discrete volume of product to be frozen is supplied to
extruder 12. Prior implementations of twin screw devices
universally are run in a continuous mode. Running in a
batch mode, co-rotating twin screws 14 and 16, according
35 to this invention, clean themselves out and leave very
little product remaining on the screw surfaces. This

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1 maximizes the freshness and the purity of the product
regardless of the frequency of product dispensing.

It should further be realized that freezing block 20
in the most preferred form of the present invention is
5 particularly advantageous in allowing operation in a
non-continuous, batch mode. Specifically, the product to
be at least partially frozen might be introduced into port
32 at a temperature 50°F (28°C) greater than the desired
surface temperature of barrel 30 and in response the
10 surface temperature of barrel 30 may increase approximately
by 5°F (2.8°C). A need then exists for the batch mode
operation of apparatus 10 of the present invention to
rapidly and specifically in approximately 1 second or less
reduce the surface temperature of barrel 30 to the desired
15 temperature and without allowing the surface temperature
to get too cold, such as below approximately -20°F (-29°C).

Specifically, in the preferred form of the present
invention, minimal wall sections are provided between
barrel 30 and channels 36. Particularly, in the most
20 preferred form for the dynamic freezing of aerated
products, the thickness of the wall sections between
barrel 30 and channels 36 and between channels 36
themselves is in the range of 1 to 5 millimeters and
preferably approximately 0.125 inch (0.318 cm) which is
25 about one eighth of the thickness for typical housings
for continuous process twin screw extruders having similar
diameter screws. It should be realized that there is no
need for a rapid (less than one second) temperature
response in a continuous process twin screw extruder as
30 conditions inside of the housing are not expected to
change by more than about 5 percent from their setpoint
over time. Additionally, typical twin screw extruders
are constructed to withstand internal pressures of up to
2500 psi (175 bars) without yielding or failure of the
35 wall sections. Operation of apparatus 10 according to
the preferred teachings of the present invention at near
atmospheric conditions and specifically at approximately

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1 50 psi (3.5 bars) reduces the need for thick wall
construction by a factor of approximately 50. The
thickness of the wall sections between barrel 30 and
channels 36 is directly proportional to the conductive
5 thermal resistance for a given material and cross-
sectional area. The heat transfer is inversely
proportional to both the thickness and thermal resistance
for a given material and cross-sectional area. Increasing
the thermal resistance, for example by increasing the
10 thickness of the wall sections, results in a decrease in
heat transfer. A reduction in heat transfer results in
a proportional increase in the time required for the
refrigerant or coolant to force the wall temperature of
barrel 30 into the desired range after the introduction
15 of product into barrel 30 at greater temperature than the
desired wall temperature. It can be appreciated that by
substantially reducing the wall section thickness, a
substantially lower thermal resistance results. Thus, by
minimizing wall section thickness, the recovery time is
20 also minimized to allow operation on a batch mode basis
according to the teachings of the present invention.

In the most preferred form, one or more flavors can be
selectively added. Such addition can take place prior to
turbulence tube 56, within turbulence tube 56, at entrance
25 port 32 of extruder 12, in extruder 12 intermediate ports
32 and 34 or after exit port 34. Addition of flavors
after exit port 34 provides the least flavor carryover
between individual servings of frozen food product and
may yield greater aromatics and flavor to the consumer.

30 According to the teachings of the present invention,
apparatus 10 is able to dynamically and at least partially
freeze an aerated food product while maintaining the
desired aeration level or overrun. Further, as apparatus
10 operates on a batch rather than a continuous process,
35 each frozen food product is produced on demand to maximize
freshness independent of the frequency that servings of
frozen food product are dispensed. Furthermore, due to

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1 the minimization of carryover between the production of
individual servings, apparatus 10 according to the
teachings of the present invention can include multiple
sources 48 of partial liquid food product as well as
5 multiple flavors. As an example, three different sources
48 could be provided such as a no fat, a low fat, and a
regular fat content base and eight different flavors could
be added so that a total of 24 different frozen food
products could be produced from a single apparatus 10.
10 Also, as each frozen food product is produced on demand,
if and when apparatus 10 goes through a cleaning cycle, it
is not necessary to discard any product contained in bag
50 and/or flavors. Further, the volume of food product
forced from bag 50 into entrance port 32 can be adjusted
15 according to the volume desired of the individual serving.
Furthermore, the volume of food product can be controlled
automatically to insure that the size of the individual
servings are consistent.

Now that the basic teachings of the present invention
20 have been explained, many extensions and variations will
be obvious to one having ordinary skill in the art. For
example, although having particular application to the
freezing and extrusion of frozen ice creams, frozen
yogurts, or semi-frozen shakes, apparatus 10 according
25 to the teachings of the present invention could be used
for cooling and at least partially freezing any particular
product which is at least partly liquid including aerated
and nonaerated beverages and non-food products. The
amount of water in the partially liquid product could
30 range from zero to one hundred percent.

Further, in the most preferred form, apparatus 10
according to the preferred teachings of the present
invention has been disclosed for the dynamic freezing of
an individual serving which will typically range in size
35 between 2 to 16 fluid ounces (60 to 470 cubic centimeters)
and is believed to have particular advantageous
application thereto. However, it can be appreciated that

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1 an individual serving can also range from between a dollop
on top of a desert prepared by another process to a cake
or family sized amount intended to be consumed by several
people and/or not to be consumed by a single individual
5 in one sitting. However, in any case, it should be
appreciated that in the preferred form, each individual
serving of whatever size is separately dynamically
frozen from each other in a noncontinuous, batch mode.

Likewise, although producing a series of multiple
10 individual servings of a food product in a batch mode is
believed to be particularly advantageous, apparatus 10
could be utilized in a continuous mode according to the
teachings of the present invention.

Thus since the invention disclosed herein may be
15 embodied in other specific forms without departing from
the spirit or general characteristics thereof, some of
which forms have been indicated, the embodiments
described herein are to be considered in all respects
illustrative and not restrictive. The scope of the
20 invention is to be indicated by the appended claims,
rather than by the foregoing description, and all changes
which come within the meaning and range of equivalency of
the claims are intended to be embraced therein.

CLAIMS

1. Method for producing a series of multiple individual servings of an at least partially frozen food product comprising the steps of: providing a food product which is at least partly liquid; providing a twin screw extruder including first and second intermeshing, screws rotatably received in a figure 8-shaped barrel and having minimal screw clearance; chilling the barrel for freezing the food product on the barrel, with rotation of the first and second screws scraping the frozen food product from the barrel and conveying the food product from an entrance port through an exit port; supplying the food product into the entrance port in discrete volumes; rotating the first and second screws within the figure 8-shaped barrel while the food product is supplied into the entrance port and continuing after the discrete volume of the food product has been supplied to convey the at least partially frozen food product through the exit port; and delaying supplying the next discrete volume of the food product.

2. The method of claim 1 wherein the food product providing step comprises the step of providing an aerated food product.

3. The method of claim 2 wherein the supplying step comprises the step of pumping the aerated food product into the entrance port at greater than atmospheric pressure.

4. The method of any preceeding claim further comprising the step of chilling at least one of the first and second screws for freezing the food product on the first and second screws.

5. The method of any preceeding claim wherein the twin screw extruder providing step comprises the step of providing the twin screw extruder including first and second co-rotating screws.

6. The method of any preceeding claim wherein the delaying step comprises the step of delaying supplying the next discrete volume of the food product until after the

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prior discrete volume has been substantially conveyed through the exit port by the rotation of the first and second screws.

7. The method of any preceeding claim wherein the twin screw extruder providing step comprises the step of providing the twin screw extruder including first and second self-wiping screws; and wherein the delaying step comprises the step of delaying supplying the next discrete volume of the food product until after the first and second screws have been rotated sufficiently to substantially prevent intermixing of the discrete volumes of the food product.

8. Device for at least partially freezing a food product which is at least partly liquid comprising, in combination: first and second substantially intermeshing screws, with each of the screws including a root having an outer periphery and a flight disposed on the root, with each flight having a crest, a leading face, and a trailing face; a housing assembly including a barrel, an entrance port in fluid communication with the barrel, and an exit port in fluid communication with the barrel, with the barrel having a figure 8-shape for rotatably receiving the first and second screws and having a configuration and size providing minimal clearance between the crests of the flights and the barrel, with the crest of the flight of the first screw closely sweeping the root of the second screw and the crest of the flight of the second screw closely sweeping the root of the first screw and with the leading face of the flight of the first screw closely sweeping the trailing face of the flight of the second screw so that the first and second screws are self-wiping; means for simultaneously rotating the first and second screws received within the barrel; means for supplying the product into the entrance port; and means for chilling the barrel for freezing the product on the barrel for being continually scraped therefrom by the crests of the flights of the first and second screws while the product is being conveyed from the entrance port to the

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exit port by the rotation of the first and second screws with the product being at least partially frozen before passing through the exit port; wherein the chilling means comprises at least one refrigerant channel extending through the housing assembly; and wherein the housing assembly comprises, in combination: a freezing block having an upstream end and a downstream end; an inlet block removably secured to and covering the upstream end, with the inlet block including the entrance port; and an exit plate removably secured to and covering the downstream end, with the exit plate including the exit port, with the barrel extending from the downstream end to the upstream end, with the refrigerant channel located exclusively in the freezing block to allow removal of the inlet block and the exit plate from the freezing block without requiring the refrigerant channel being disconnected from the source of refrigerant.

9. The device of claim 8 wherein multiple refrigerant channels extend through the housing assembly spaced closely adjacent and parallel to the barrel, with the housing assembly made of highly thermally conductive material.

10. Device for at least partially freezing a food product which is at least partly liquid comprising, in combination: first and second substantially intermeshing screws, with each of the screws including a root having an outer periphery and a flight disposed on the root, with each flight having a crest, a leading face, and a trailing face; a housing assembly including a barrel, an entrance port in fluid communication with the barrel, and an exit port in fluid communication with the barrel, with the barrel having a figure 8-shape for rotatably receiving the first and second screws and having a configuration and size providing minimal clearance between the crests of the flights and the barrel, with the crest of the flight of the first screw closely sweeping the root of the second screw and the crest of the flight of the second screw closely sweeping the root of the first screw and with the leading face of the flight

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of the first screw closely sweeping the trailing face of the flight of the second screw so that the first and second screws are self-wiping; means for simultaneously co-rotating the first and second screws received within the barrel; means for supplying the product into the entrance port; and means for chilling the barrel for freezing the product on the barrel for being continually scraped therefrom by the crests of the flights of the first and second screws while the product is being conveyed from the entrance port to the exit port by the rotation of the first and second screws with the product being at least partially frozen before passing through the exit port.

11. The device of claim 10 wherein the chilling means comprises multiple refrigerant channels extending through the housing assembly spaced closely adjacent and parallel to the barrel, with the housing assembly made of highly thermally conductive material.

12. The device of claim 11 wherein the refrigerant channels are spaced in the range of 1 to 5 millimeters from the barrel and the refrigerant channels are spaced in the range of 1 to 5 millimeters from each other.

13. The device of claim 11 or 12 wherein the refrigerant channels extend through the housing assembly in first and second rows, with the second row having greater radial spacing from the barrel than the first row.

14. The device of any claim 10-13 wherein the screws are positioned parallel to each other.

15. The device of any claim 10-14 wherein the faces of the flights of the screws are not linear and have an increasing size from the crests to the roots.

16. Device for at least partially freezing a food product which is at least partly liquid comprising, in combination: first and second substantially intermeshing screws, with each of the screws including a root having an outer periphery and a flight disposed on the root, with each flight having a crest, a leading face, and a trailing

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face; a housing assembly including a barrel, an entrance port in fluid communication with the barrel, and an exit port in fluid communication with the barrel, with the barrel having a figure 8-shape for rotatably receiving the first and second screws and having a configuration and size providing minimal clearance between the crests of the flights and the barrel, with the crest of the flight of the first screw closely sweeping the root of the second screw and the crest of the flight of the second screw closely sweeping the root of the first screw and with the leading face of the flight of the first screw closely sweeping the trailing face of the flight of the second screw so that the first and second screws are self-wiping; means for simultaneously rotating the first and second screws received within the barrel; means for supplying the product into the entrance port; means for chilling the barrel for freezing the product on the barrel for being continually scraped therefrom by the crests of the flights of the first and second screws while the product is being conveyed from the entrance port to the exit port by the rotation of the first and second screws with the product being at least partially frozen before passing through the exit port; and means for chilling the first and second screws for freezing the product on the leading and trailing faces and the roots of the first and second screws for being continually scraped therefrom by the flights of the first and second screws.

17. The device of claim 16 wherein each of the screws comprises, in combination: first and second axial ends; and wherein the screw chilling means comprises, in combination: a cylindrical bore extending axially from the first axial end towards but axially spaced from the second axial end; a cylindrical post having a diameter slightly smaller than the diameter of the cylindrical bore and received in the cylindrical bore; and means for passing a refrigerant or coolant between the cylindrical post and the cylindrical bore.

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18. The device of claim 17 wherein the passing means comprises, in combination: an inlet conduit, with the cylindrical post having a cylindrical outer face and an axial free end located within the cylindrical bore, with the inlet conduit extending axially from the axial free end of the cylindrical post; a return conduit formed in the cylindrical post and extending from a point axially spaced from the axial free end of the cylindrical post; and apertures extending from the cylindrical outer face and intersecting with the return conduit.

19. The device of any claim 16-18 wherein the supplying means comprises, in combination: means for supplying the product into the entrance port in multiple, discrete volumes, with the simultaneously rotating means rotating the screws sufficiently between the volumes such that the at least partially frozen product of one volume has substantially passed through the exit port without carryover before the next volume of the product is fed such that the device delivers product in a noncontinuous, batch mode.

20. The device of claim 19 wherein the supplying means comprises means for supplying the product in the form of an aerated food product.

21. The device of claim 20 wherein the supply means comprises means for forcing the aerated food product into the entrance port at greater than atmospheric pressure.

22. The device of claim 21 wherein the forcing means comprises means for pumping the aerated food product into the entrance port.

23. The device of any claim 16-22 wherein the ratio of the radius of the flight at the crest to the radius at the root is in the range of 1.01 to 1.2.

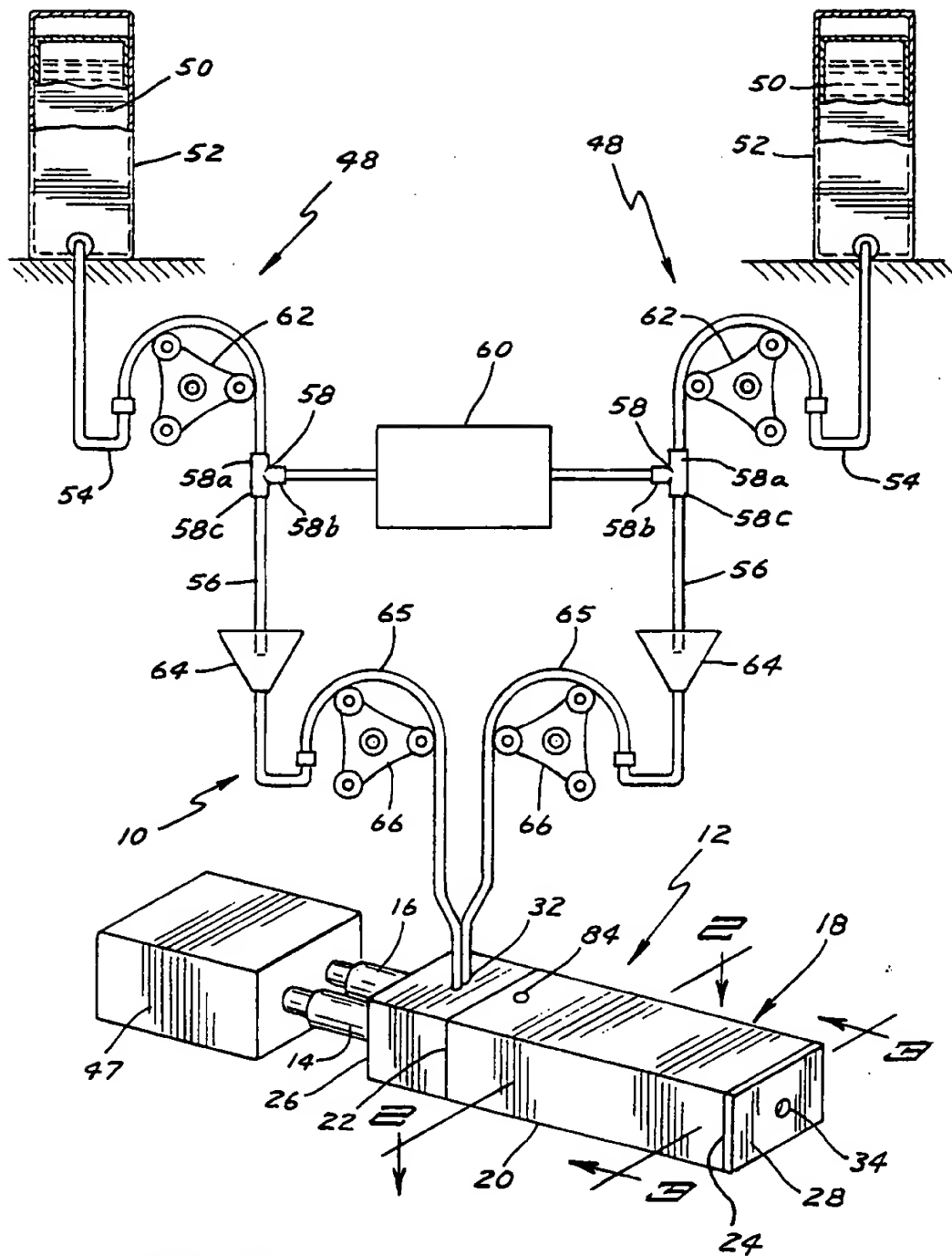
24. The device of any claim 16-23 wherein a ratio of the clearance between the crests of the flights and the barrel and the radius of the flights of the screws is in the range of 0.002 to 0.010.

25. The device of any claim 16-24 wherein the ratio of

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the length of the barrel to the outside diameter of the flights of the screws is in the range of 1.5 to 6.0.

26. The device of any claim 16-25 wherein the flights of the screws have a pitch in the range of 0.4 to 2.4 times the diameters.



2/4

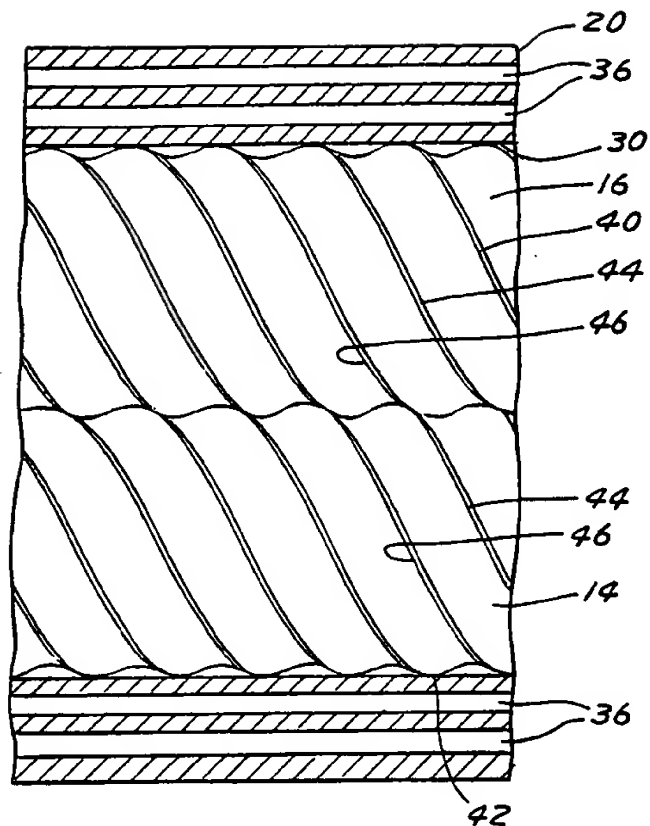


FIG. 2

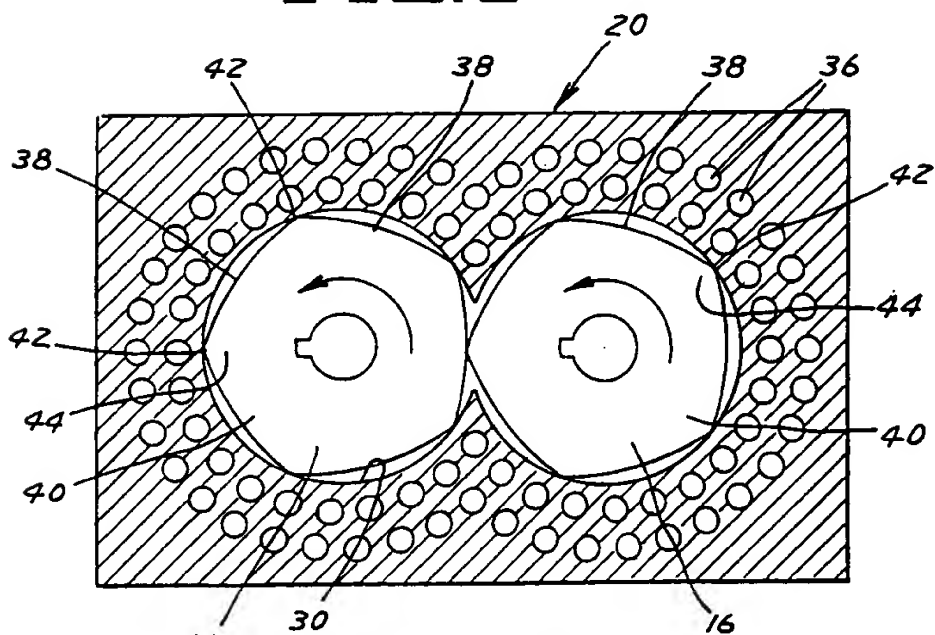


FIG. 3A

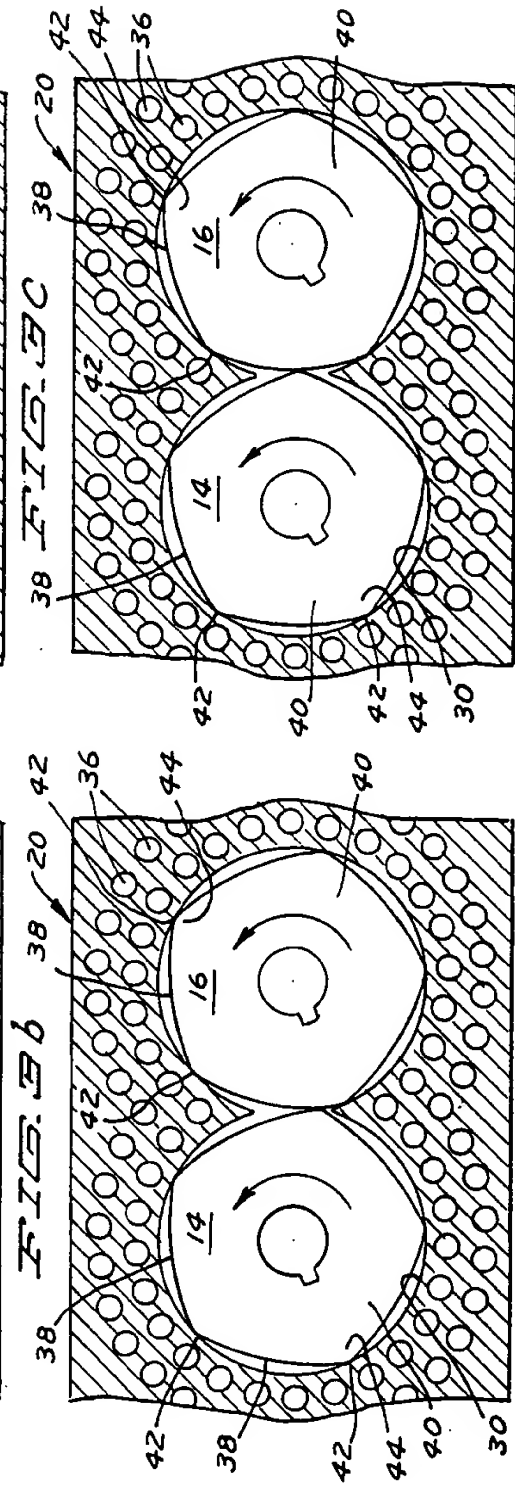
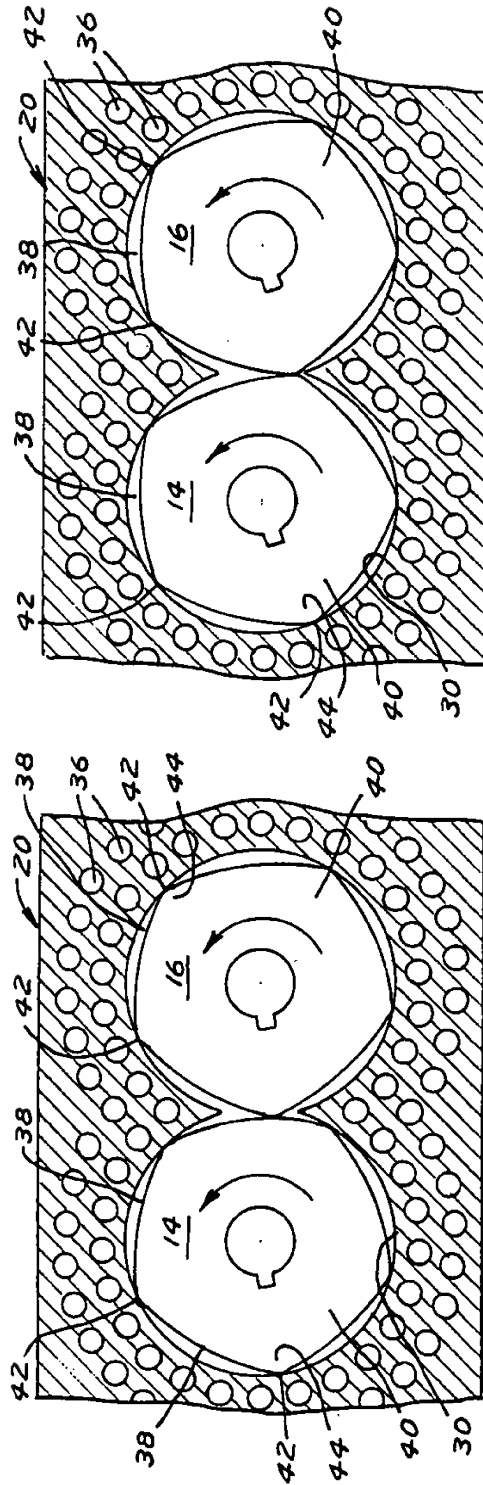


FIG. 3a

FIG. 3b

INTERNATIONAL SEARCH REPORT

Inter national Application No
PCT/US 97/18938

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A23G9/16 A23G9/20 A23G9/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A23G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 345 781 A (FELS ULRICH ET AL) 13 September 1994 cited in the application	1-5, 8-11, 14-17, 23-26
A	see abstract see figures see column 3, line 4 - column 13, line 60 --- -/--	6,7,12, 13,18-22

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"S" document member of the same patent family

Date of the actual completion of the international search

27 January 1998

Date of mailing of the international search report

04/02/1998

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INTERNATIONAL SEARCH REPORT

Inter national Application No
PCT/US 97/18938

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